

EFFICIENTLY CHANGING THE

ONCE developed chiefly for physics research, high-energy, high-average-power lasers are now used in a diverse range of applications, such as high-speed manufacturing, demolition, and national defense technologies. These lasers operate in the infrared portion of the electromagnetic spectrum, producing light beams with wavelengths of about 1,000 nanometers. However, infrared light is not always the best color for every application. For example, ceramics and plastics are more efficiently machined with ultraviolet light, green light is better for cutting the copper metal used in electronic circuit boards, and the targets for high-energy-density physics experiments are often designed to require light at wavelengths other than infrared.

The color of laser light is changed with wavelength conversion crystals, but each type of crystal has performance drawbacks. Barium borate crystals have excellent thermal properties but cannot be grown to the sizes needed for some applications. Cesium lithium borate crystals can be grown to large apertures for large-beam-size lasers, but these crystals degrade rapidly when exposed to air. Potassium di-deuterium phosphate (DKDP) crystals are well suited for high-pulse-energy wavelength conversion, but their relatively poor thermal properties limit their performance on high-average-power systems.

A team of researchers from Lawrence Livermore and Crystal Photonics, Inc. (CPI), of Sanford, Florida, has developed a more efficient and compact converter crystal using yttrium calcium oxyborate (YCOB). The team, led by Livermore physicists Christopher Ebberts and Zhi Liao, received a 2006 R&D 100 Award for the YCOB innovation. This R&D 100 Award is the third for Ebberts, who works in the National Ignition Facility Programs Directorate. (See *S&TR*, September 1999, pp. 8–9; October 2003, pp. 14–15.)

Dealing with the Heat

The YCOB crystal is designed for Mercury, Livermore's large-aperture, high-average-power laser. Intended as a prototype of a fusion laser driver, Mercury has a high repetition rate (10 hertz), and its average power is about 0.5 kilowatt. In addition, it operates for hours at a time, which poses tough cooling challenges. Scientists are using the Mercury laser to probe the fundamental interactions of light and matter, and many of these experiments require the conversion of infrared light to green.

The most basic wavelength conversion process, known as second-harmonic generation, converts the input laser wavelength into light with half the incident wavelength. Thus, infrared light



The Livermore development team for the high-average-power wavelength converter: (first row, from left to right) Noel Peterson, Manuel Carrillo, Bob Kent, Kathleen Schaffers, Chris Ebberts, Kathy Allen, Zhi Liao, Camille Bibeau, Tony Ladrán, and Steve Mills; (back row) Rod Lanning, Stanley Oberhelman, Greg Rogowski, Everett Utterback, Andy Bayramian, Bruce Warner, Barry Freitas, Rob Campbell, Dave Van Lue, Steve Telford, and Nick Schenkel. Not pictured: Peter Thelin, Kathy Alviso, and Steve Payne.

COLOR OF LASER LIGHT

with a wavelength of 1,047 nanometers, when propagated through a crystal, is output as green light with half of the original wavelength (523.5 nanometers). When the speed of light for the two colors in the crystal is identical, 100 percent of the infrared light can be transformed to the second harmonic (green). However, as the crystal heats up, the speed differs, and the light will oscillate between green and infrared, which reduces the conversion efficiency. To eliminate this problem, Livermore researchers use four thin DKDP crystals as wavelength converters and individually cool each one with a sapphire plate.

The complexity of the DKDP converter led Livermore and CPI to explore the potential of YCOB crystals in a 1997 project funded by Livermore's Laboratory Directed Research and Development Program. Results from the initial project showed that YCOB was extremely insensitive to heating, but other crystals were more efficient at converting the wavelength of low-pulse-energy lasers. The team determined, however, that if YCOB crystals could be produced in large sizes, they held potential for use on high-pulse-energy, high-average-power lasers. In 2005, with funding from the Mercury project, the team began scaling the volume of YCOB.

Clear, Crack-Free Crystals

The 1997 project team grew 10-centimeter-long boules of YCOB crystal with 2.5-centimeter apertures, from which they cut high-optical-quality YCOB plates with volumes of 1 cubic centimeter. By June 2005, the team had improved the crystal's internal optical quality and had grown clear, crack-free crystals that

measure 7.5 centimeters in diameter and 24 centimeters in length, representing a 27-fold increase in volume. The converter plates cut from these large boules measure 5.5 by 8.5 centimeters with a thickness of 1.6 centimeters.

A single, side-cooled YCOB crystal has replaced the four-crystal assembly in Mercury. In a demonstration experiment, the new wavelength converter achieved 50-percent power conversion, using 450 watts of infrared light to generate a world-record 225 watts of green light. In this experiment, the laser operated for 30 minutes, performing 18,000 shots at 10 shots per second, without any degradation in performance from heating. The Livermore-CPI team is working to reduce the pulse length from 15 to 5 nanoseconds, which should increase the conversion efficiency to 80 percent.

"The thermal robustness of the single-plate YCOB wavelength converter allows for a more efficient laser system," says Ebbers. Replacing the four DKDP crystals and their sapphire cooling plates with one YCOB crystal also reduces the size of the system, which lowers the manufacturing cost. As a result, high-average-power lasers can be considered for diverse applications from exploring the interactions of light with matter to developing a suite of tools for homeland security and national defense. Other lasers, such as Livermore's solid-state heat capacity laser, could potentially take advantage of this converter as well.

With its strong advantages over other crystals, the YCOB wavelength converter crystal promises a new era of laser research and laser systems with an easy route to green.

— Arnie Heller

Key Words: high-average-power laser, Mercury laser, potassium di-deuterium phosphate (DKDP) crystal, R&D 100 Award, wavelength conversion, yttrium-calcium-oxyborate (YCOB) crystal.

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Invisible infrared light with a wavelength of 1,047 nanometers enters the laser system from the right and interacts with the yttrium-calcium-oxyborate crystal in the center of the holder. The crystal shifts the infrared light to green light with a wavelength of 523.5 nanometers.

